Toward a 3rd Generation Sediment Dynamics Sensing System

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LONG-TERM GOALS

The central goal of this research is a deeper understanding of the dynamic adjustment of mobile sandy sediments to the variable fluid forcing the nearshore zone and inner continental shelf at small (1-cm to 10-m) and intermediate (10-m to 100-m) horizontal scales. The effort is motivated by the dual need to develop more realistic models of fluid-sediment interactions in these environments, and for suitable measurement techniques to make the observations necessary to adequately test the models.

OBJECTIVES

The objective of the proposed project is to advance the state-of-the-art of acoustic remote sensing systems for sediment and fluid dynamics studies in the wave-current bottom boundary layer. The particular focus of this project is the remote (and routine) measurement of bottom stress in energetic combined flows above mobile beds.

APPROACH

The approach involves:

- development of a new multi-frequency, several-mm vertical resolution, pulse-coherent Doppler profiler; and

- laboratory experiments in a particle-laden turbulent wall jet comparing turbulence-resolving measurements made with the new Doppler profiler to those made by Particle Imaging Velocimetry (PIV), for both hydrodynamically smooth and rough walls.

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WORK COMPLETED

The design of the 5-transducer array was completed and contracted out to a local company for manufacture. The array was assembled and tested in July. After several days immersion, we found water had leaked into the assembly. Additional seal plates were designed and machined, allowing the individual mechanical elements of the array to be leak-tested individually. The source of the leak was finally identified in late August: faulty bonding between the potting compound and the metal housing in three of the transducers. These 3 transducers have been shipped back to the manufacturer for repair or replacement. Fortunately, we had a spare transducer, so we have been able to proceed with the system tests with the three non-leaky transducers.

The data acquisition and control (DAQC) software has been completed, and undergone several phases of testing and revision. As of 13 September, the software was sufficiently operational to permit a test of the 3-transducer version of the system in the jet tank facility (described in Hay, 1991). This test was carried out on 15 September, and was completely successful. Following the mid-September test, the electronics permitting the backscattered signal to be received on the transmitting transducer have been implemented, and a number of improvements both to the receivers and to the DAQC software have been made. Software engineer Robert Craig has been developing the data acquisition code. Ocean Acoustics Technologist Wesley Paul has been responsible for the design and assembly of the signal conditioning circuitry. After taking a year to give industry a try, Wes returned to Dalhousie in December 2005. His skills have contributed significantly (indeed have been essential) to the rapid progress made since then.

Len Zedel has continued to develop and refine his model simulating the effects of scatterer advection and turbulent reconfiguration on the phase noise in coherent Doppler systems, and has prepared a draft manuscript on the model which is soon to be submitted. The model has proved to be an invaluable guide throughout the design process, especially in relation to testing our ideas for the design geometry, the expected velocity accuracy and statistics, and different ambiguity resolution schemes.

The jet apparatus has been modified to accommodate the PIV system, including in particular the periscope assembly (for ducting the laser beam through the air-water interface into the tank). M.Sc. student Stephanie Moore has initiated her experiments on broadband sound scattering from turbulent suspensions in the jet tank as part of her thesis work.

RESULTS

Figure 1 shows an example result from the jet tank tests. The system was configured to sample a profile across the jet, perpendicular to the jet axis. The upper panel is the backscatter at a single-frequency (1.5 MHz), showing the ca. 10-cm wide range interval occupied by the sediment-laden jet. The lower panels are the resolved velocities from the two slant-beam transducers, U being the axial component, V the tranverse component. The pump driving the jet was turned off at $t = 10$ s, so the velocity and backscatter signals subsequently decay with time as the pump gradually slows down. The large-scale eddy structure of the jet is beautifully resolved in both velocity components at cm-scales. Note in particular the axial component, and the ca. 5-cm scale for the halfwidth of the jet. As this scale is comparable to the thickness of the wave bottom boundary layer, and the time scales of the eddy structures are $\geq O(0.1)$ s, these results indicate that we will be able to resolve the vertical structure of

the horizontal flow within the turbulent wave bottom boundary layer (WBBL), and furthermore that we will be able to resolve the structure of large-scale turbulent eddies in the WBBL.

There are some bad data points in these early results from the new system. The bad data occur in clusters, and are associated with very low correlations due to the high intensity turbulence in the jet. We are in the process of implementing a more robust algorithm which will substantially reduce these occurrences.

IMPACT/APPLICATIONS

The results embodied in Figure 1 represent a significant achievement. The new system operates at 4 acoustic frequencies simultaneously, at a 10 pulse-pair ensemble-average acquisition rate of 60 Hz along a 50-cm profile with 3-mm range resolution. For comparison, this is 4x the number of frequencies, 5/3x the number of beams, 2x the range resolution, and 3x the profile acquisition rate of our old-generation 3-beam single-frequency CDP. With an expected increase of at least 4x in the velocity accuracy, these numbers represent a 160-fold increase in performance.

We are able to resolve the 2-d structure of the larger-scale turbulence in a moderately high Reynolds number jet, and therefore expect to be able to resolve the large eddies within, and vertical structure of, the WBBL down to sub-cm scales for the first time. Thus, while we cannot quite yet claim to have made a breakthrough, we are very, very close to doing so.

The significance of this project resides in the fact that bottom stress over mobile beds is not well-constrained for the range of combined wave-current forcing conditions encountered in nearshore and continental shelf environments. The measurements obtained with the new system will enable the independent determination of the bottom stress in wave and wave-current boundary layers, thereby filling a long-standing weakness in our ability to constrain models of mobile bed adjustment. Because we are using multiple frequencies to insonify the same measurement column simultaneously, we will be able to resolve the size-concentration ambiguity at the time scales of the larger eddies and therefore measure the large-eddy fluxes of suspended sediment. Thus, results obtained with the new system, in conjunction with high resolution measurements of small-scale bed topography, will provide a fundamentally new and important basis for testing existing wave-current boundary layer theories, existing bedform development and sediment transport models, and the large-eddy simulation models of fluid-sediment interactions which are currently under development.

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Zedel, L. and A.E. Hay, 1999. A Coherent Doppler Profiler for high resolution particle velocimetry in the ocean: laboratory measurements of turbulence and particle flux, *J. Atmos. and Ocean. Tech.*, *16(8)*, 1102-1117.

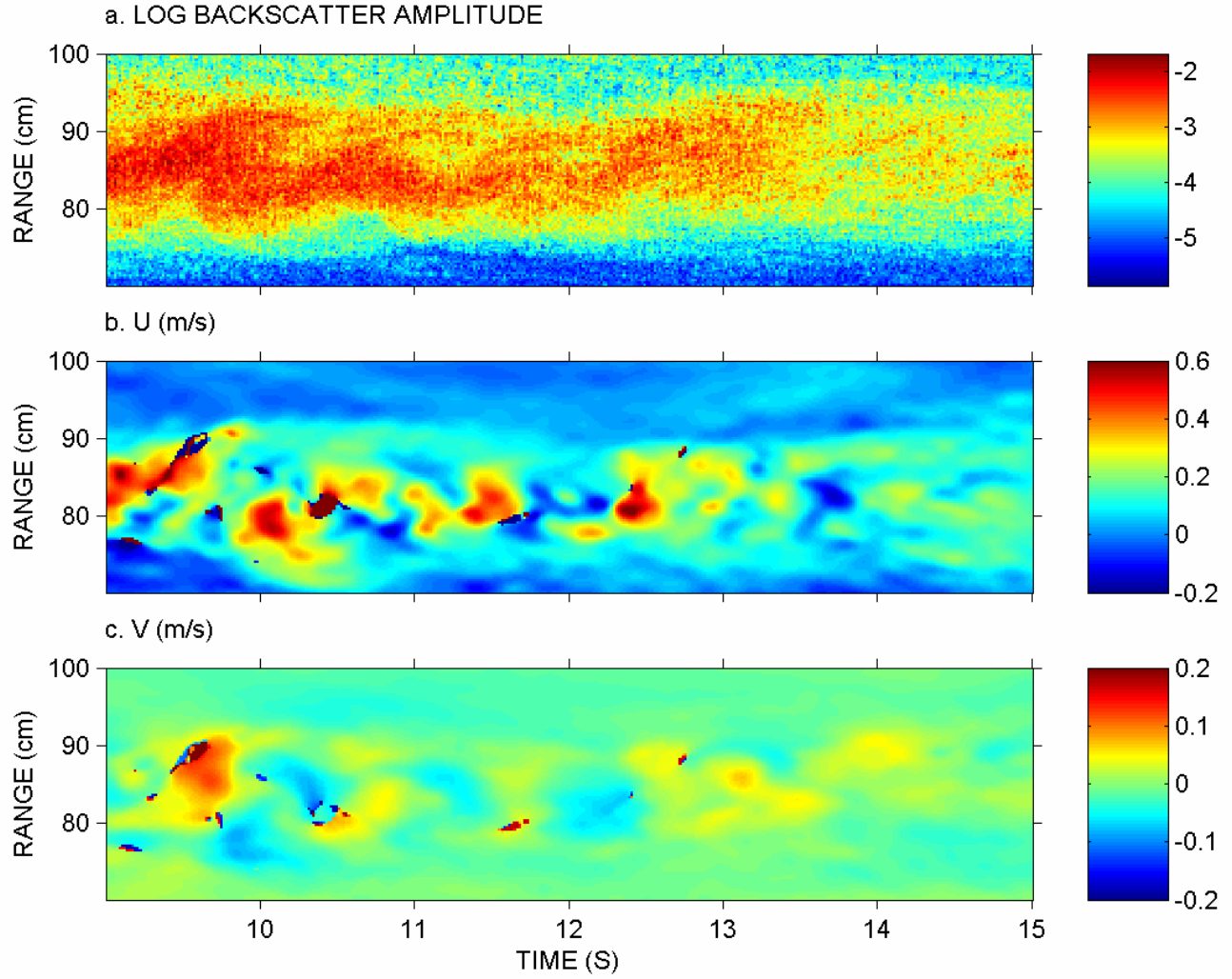a. LOG BACKSCATTER AMPLITUDE

b. U (m/s)

c. V (m/s)

Figure 1. Results from a test run with the multi-frequency coherent Doppler profiler, operating in 2-beam mode at 1.5, 1.75, 2.0 and 2.25 MHz, in the particle-laden jet facility. (a) scattering amplitude at 1.5 MHz; (b) axial velocity; (c) transverse velocity.